
SLIC

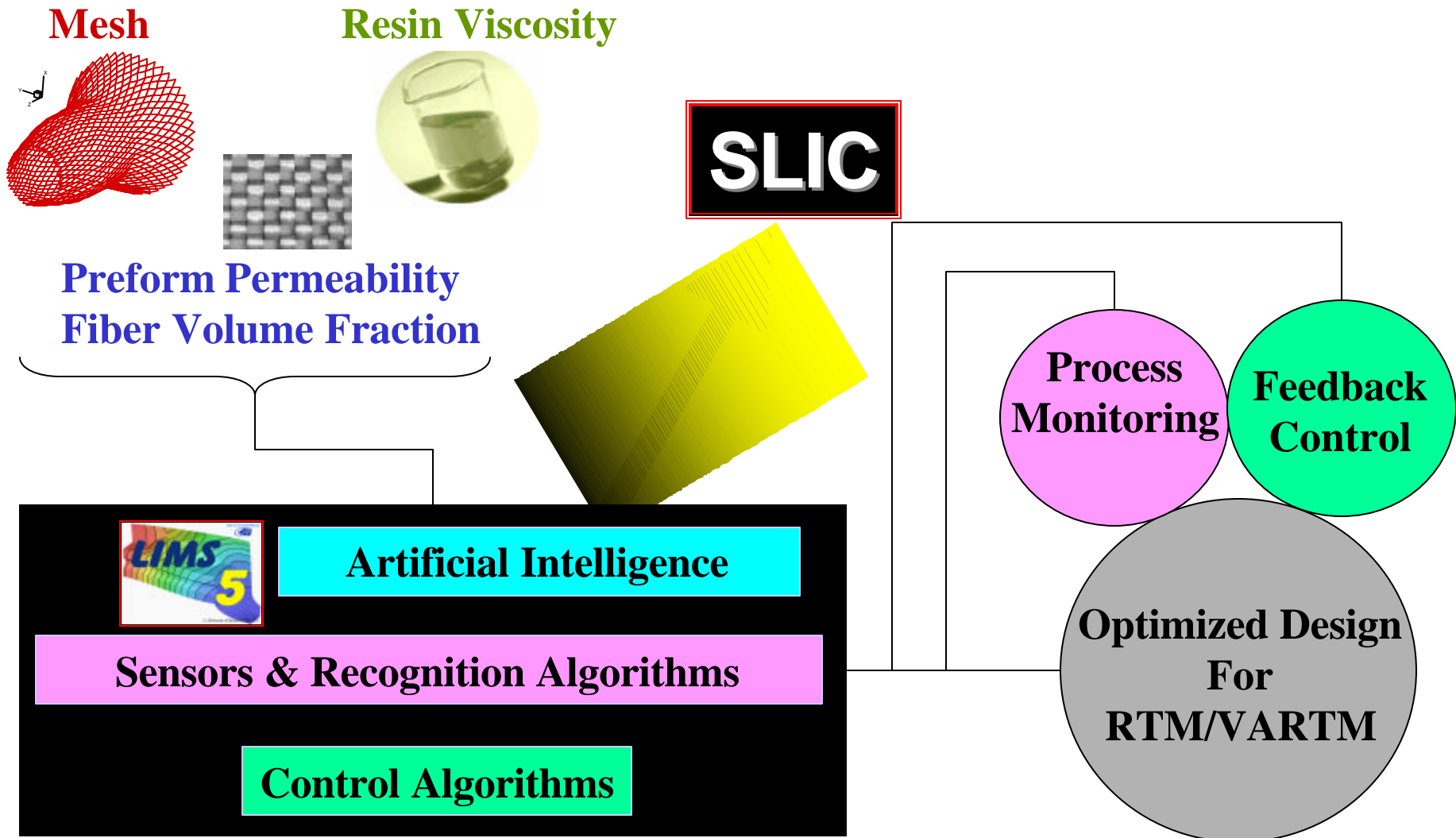
SIMULATION-BASED LIQUID

INJECTION CONTROL

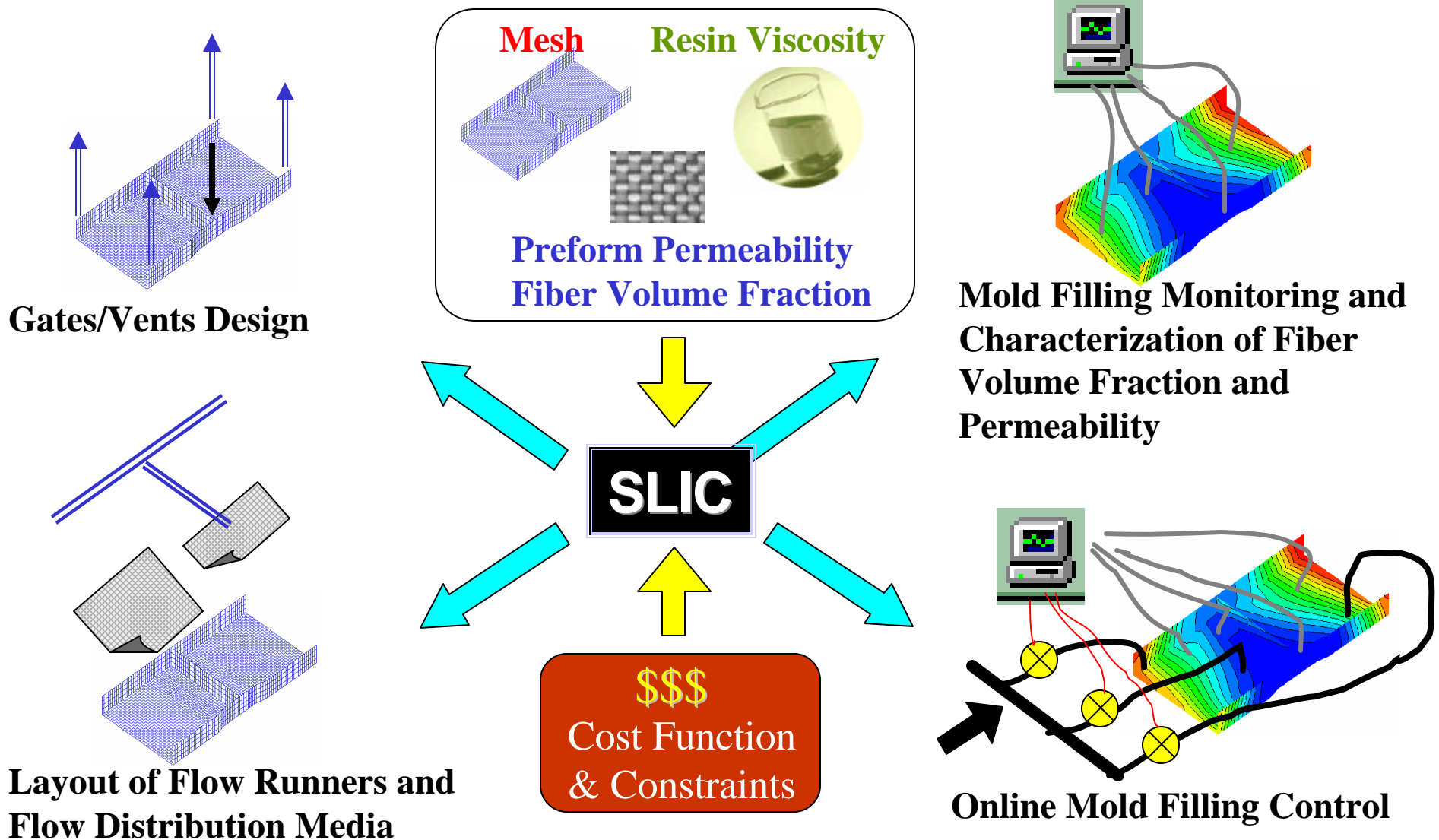
Kuang-Ting Hsiao

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Simulation-based Liquid Injection Control: Philosophy



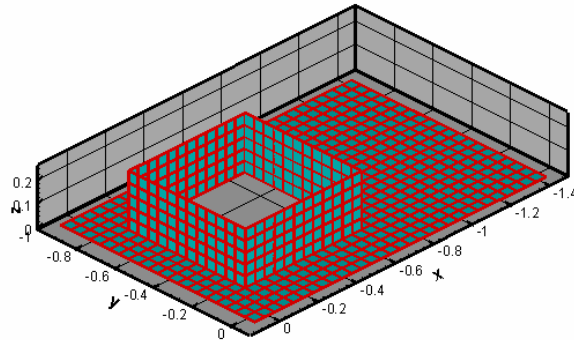
Features of SLIC



Case 1: Optimize Gate & Vent Locations



Input



Length=1.50m
Width=1.00m
Height=0.20m

Thickness = 0.01m
 $K_{xx} = K_{yy} = 1E-10 \text{ m}^2$
 $V_f=0.5$

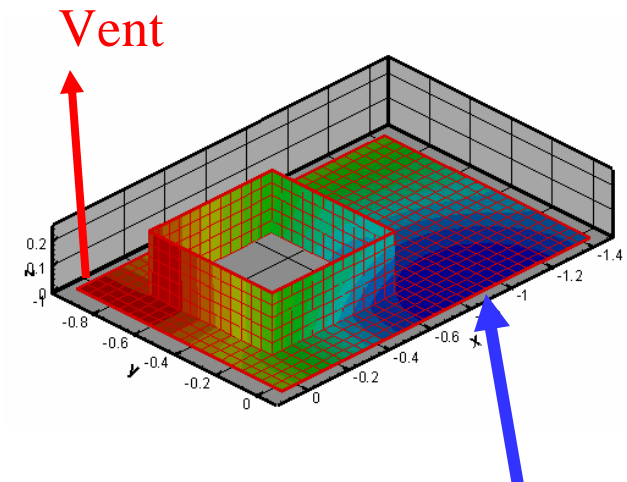
Resin Viscosity = 0.12 Pa-sec = 120 cps

Injection Pressure = $3.03E+5 \text{ Pa}$
Vent Pressure = $1.01E+5 \text{ Pa}$

Cost Function

SLIC

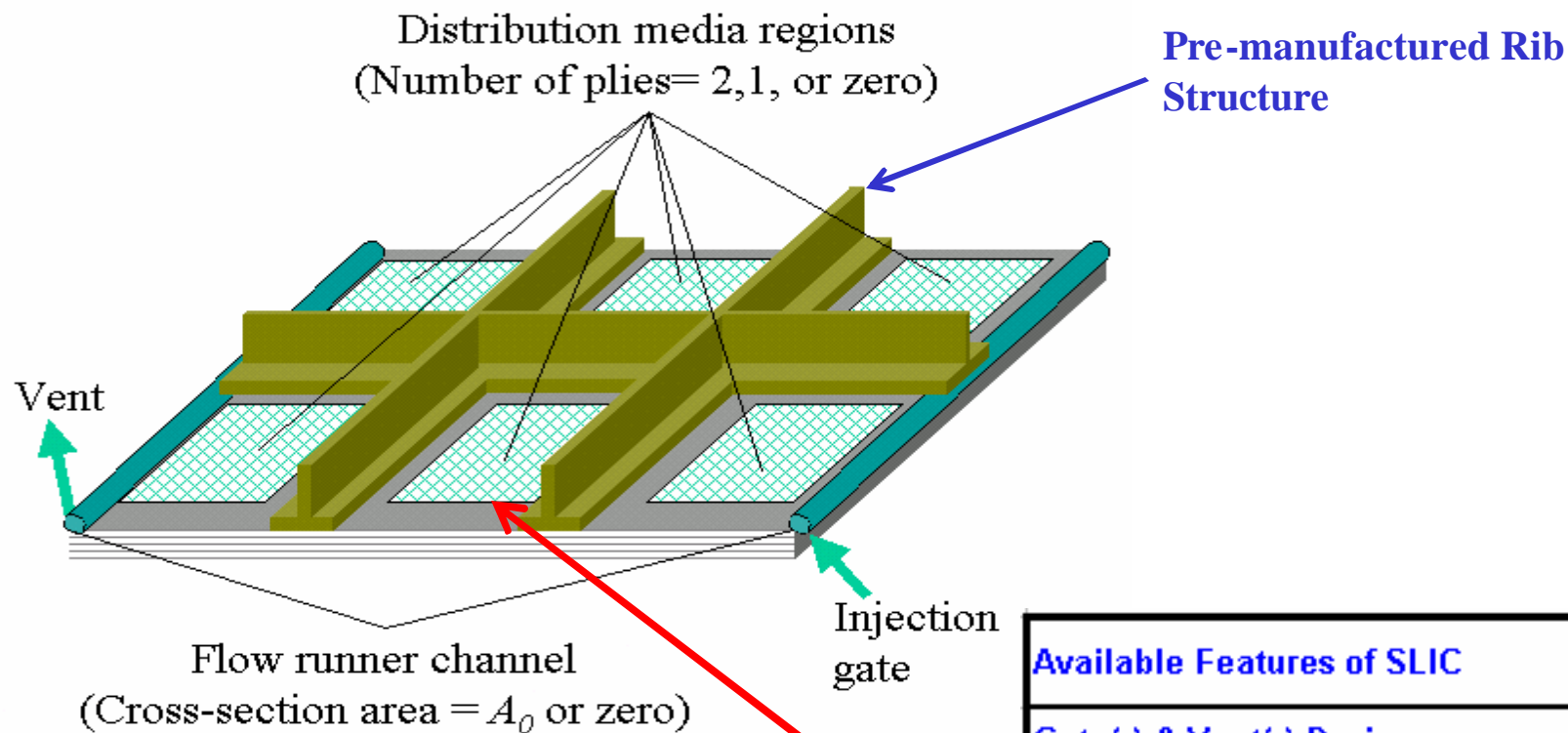
Optimized Mold Filling



Injection Gate

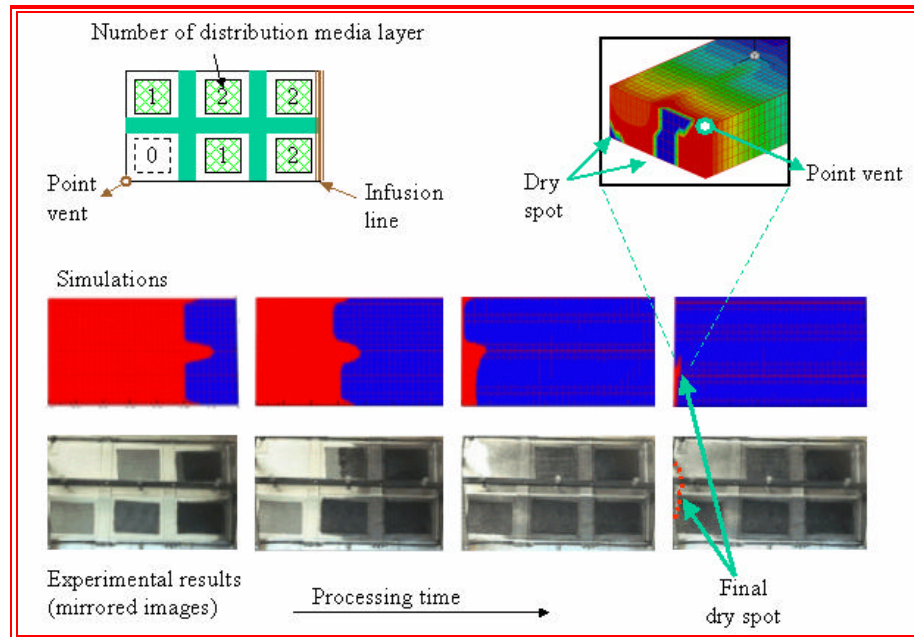
| Available Features of SLIC | Features Used |
|---|---------------|
| Gate(s) & Vent(s) Design | x |
| Flow Distribution Network Design | |
| Mold Filling Monitoring & Online Characterization of Permeability/Volume Fraction | |
| Online Mold Filling Flow Control | |

Case 2: A VARTM/Co-Cure Case Study

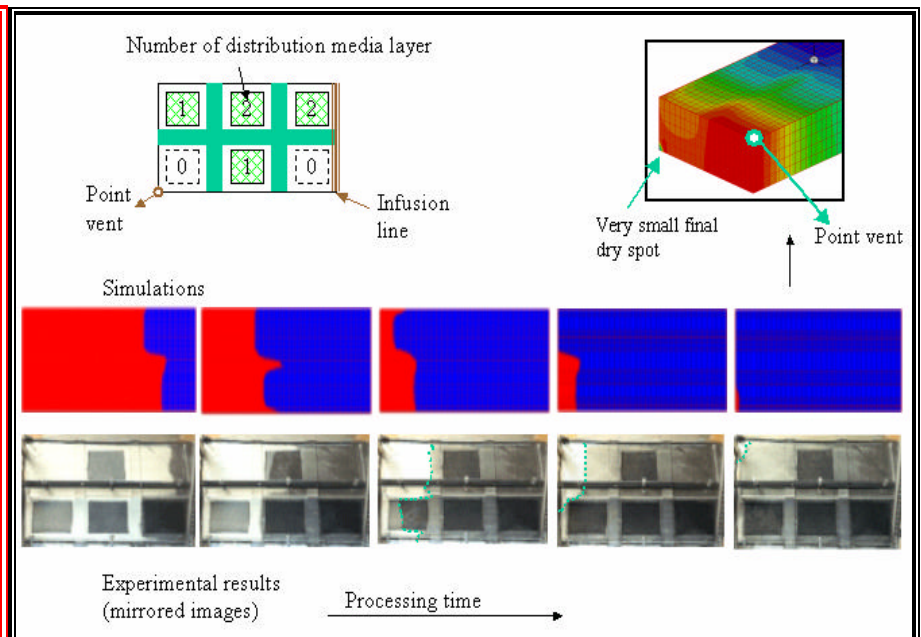


| Available Features of SLIC | Features Used |
|---|---------------|
| Gate(s) & Vent(s) Design | |
| Flow Distribution Network Design | x |
| Mold Filling Monitoring & Online Characterization of Permeability/Volume Fraction | x |
| Online Mold Filling Flow Control | |

Intuitive (Trial-And-Error) Design vs. SLIC's Design (Case 2)



Final (fourth) intuitive design



SLIC's design

| | Dry spot content | Fill time | Number of experiments |
|-----------------------------------|------------------|-----------|-----------------------|
| Trial-and-error intuitive design | 0.851% | 10.87 min | 4 |
| GA/simulation-based design (SLIC) | 0.034% | 13.05 min | 1 |

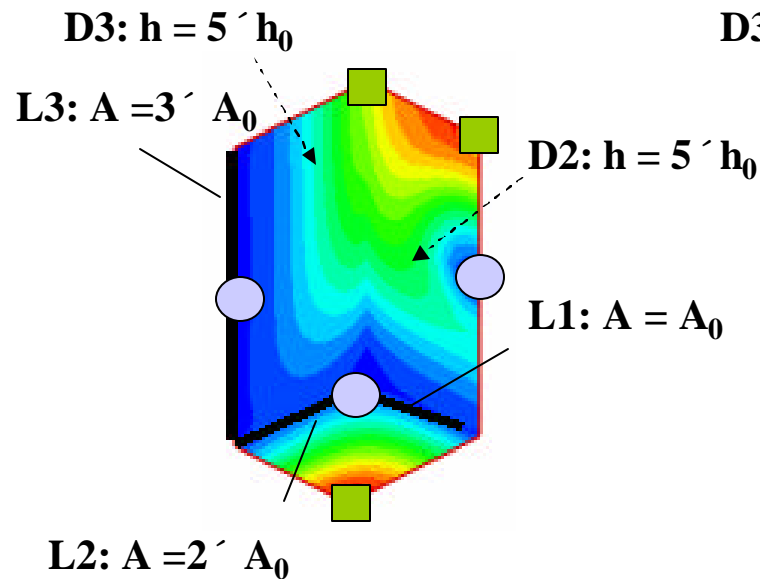
Case 3: A VARTM Case Study



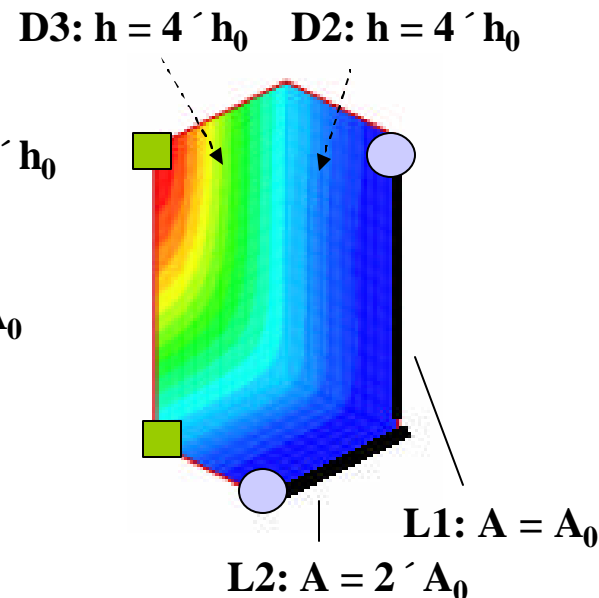
D: Distribution Media
L: Flow Runner

h_0 : Thickness of 1-ply distribution media
 A_0 : Cross-section Area of reference Flow Runner

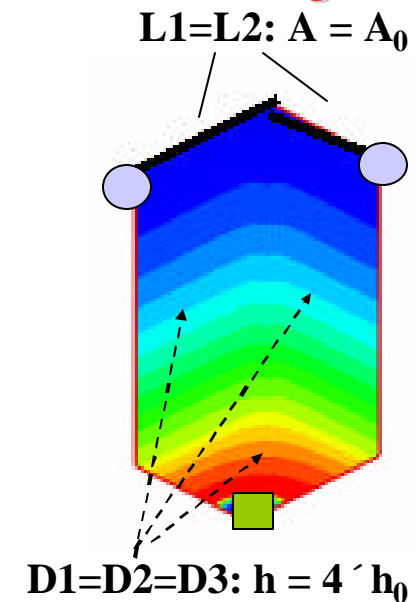
Design 1



Design 2

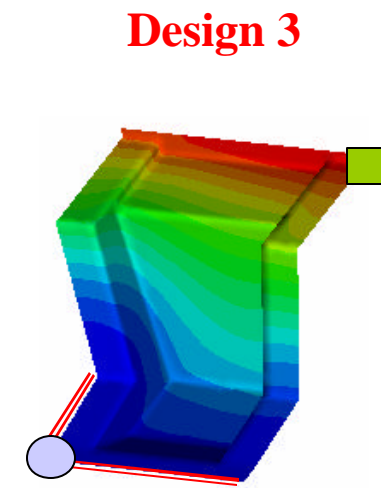
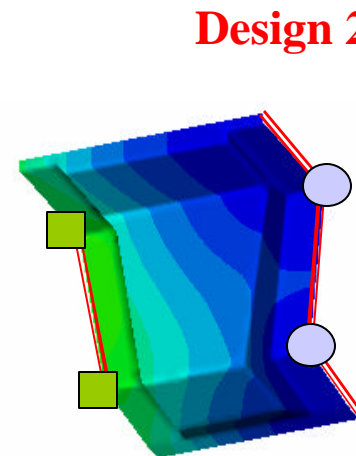
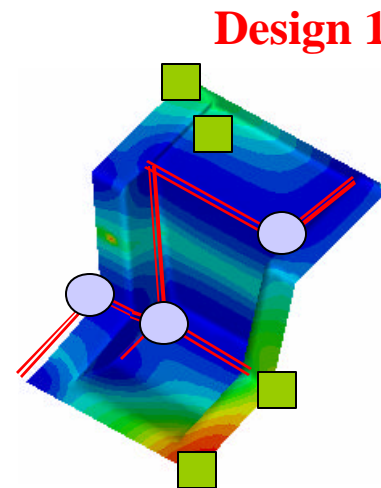
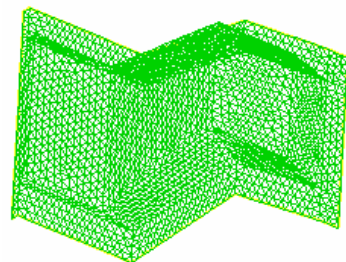
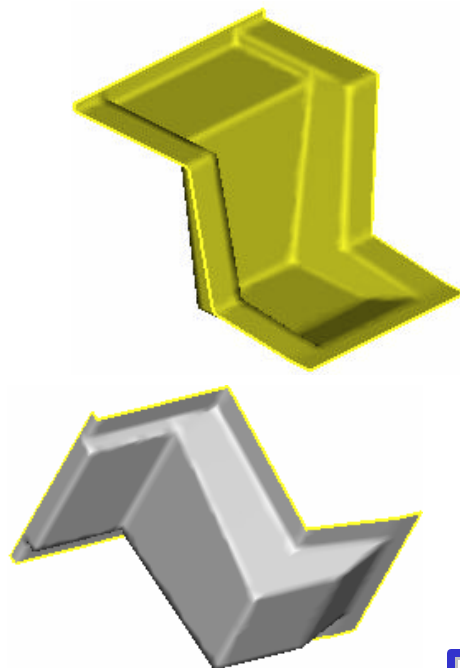


Design 3



| | Design 1 | Design 2 | Design 3 |
|---|----------|-----------|------------|
| SLIC Gates/Vents Optimization | Yes | No | No |
| SLIC Flow Distribution Network Optimization | Yes | Yes | No |
| Fill Time | 28min | 1hr 08min | 1hr 38 min |
| Number of Empty Nodes/Number of Nodes | 0/948 | 0/948 | 4/948 |

Case 4: Steps on a Boat Deck (VARTM with Flow Runners)



○ Gate

■ Vent

— Flow Runner

| | Design 1 | Design 2 | Design 3 |
|---------------------------------|----------|----------|----------|
| SLIC Gates & Vents Optimization | Yes | Yes | Yes |
| Number of Gates | 3 | 2 | 1 |
| Number of Vents | 4 | 2 | 1 |
| Fill Time Without Flow Runner | 6min | 15min | 1hr |
| SLIC Flow Runner Optimization | Yes | Yes | Yes |
| Fill Time With Flow Runners | 2min | 14min | 12min |

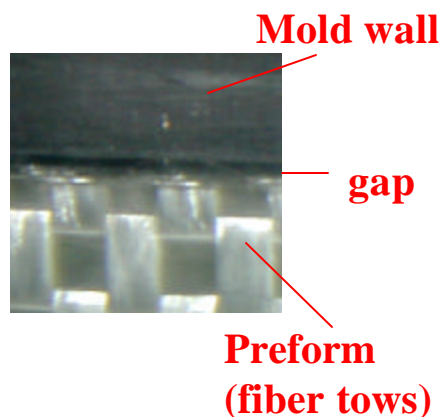
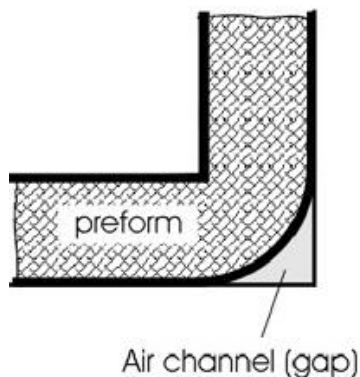
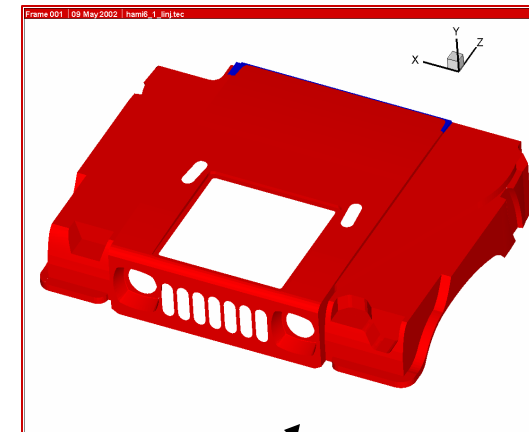
Permeability Variation in Process



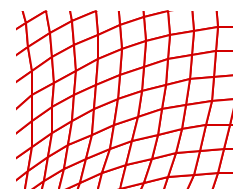
- ✓ •Injection Pressure/Port
- ✓ •Vent Pressure/Port
- ✓ •Resin Viscosity
- ? •Fiber Volume Fraction
- ? •Permeability of the the Preform

LIMS

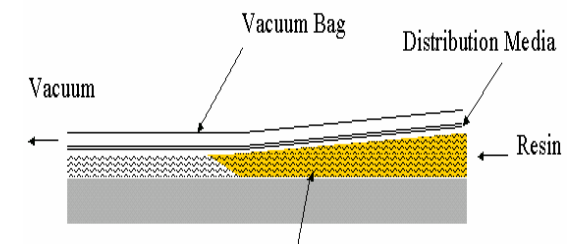
Characterization Challenges !



Deformed fabric
Draping over
a tool surface

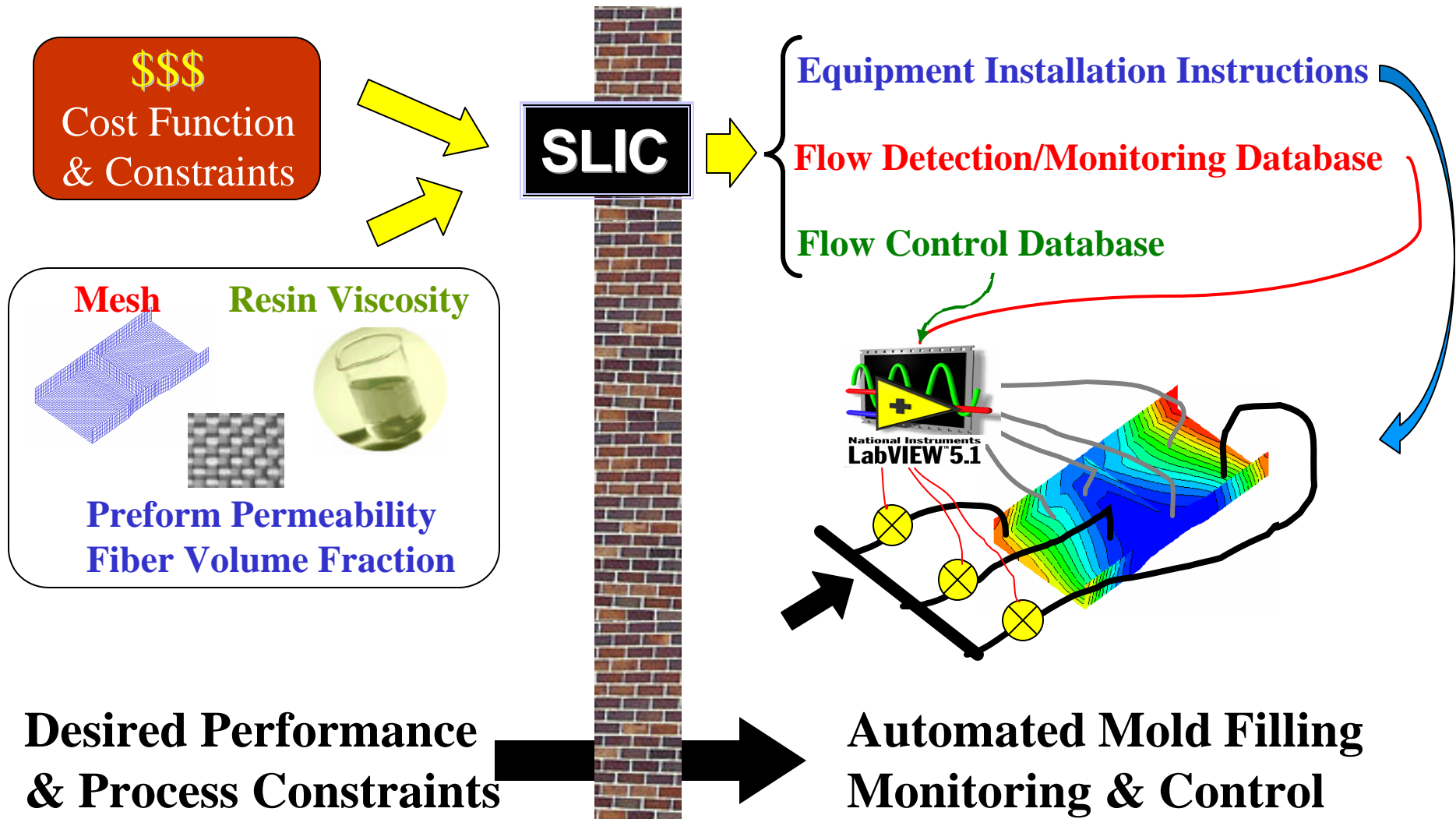


K and V_f change

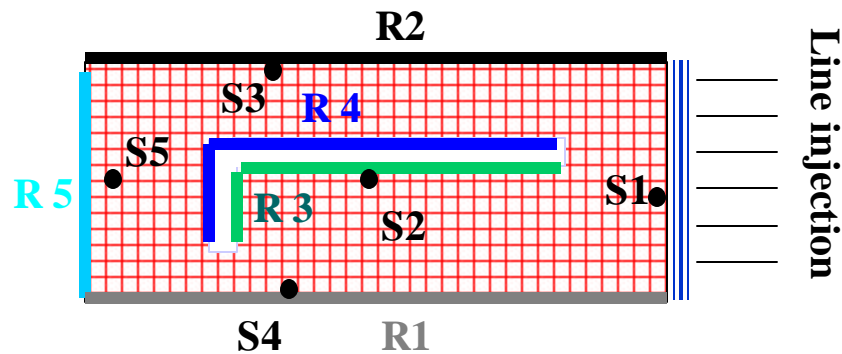


K and V_f Change due to the Compaction Variation in VARTM

Streamlined Flow Monitoring & Control - From Design To Automation

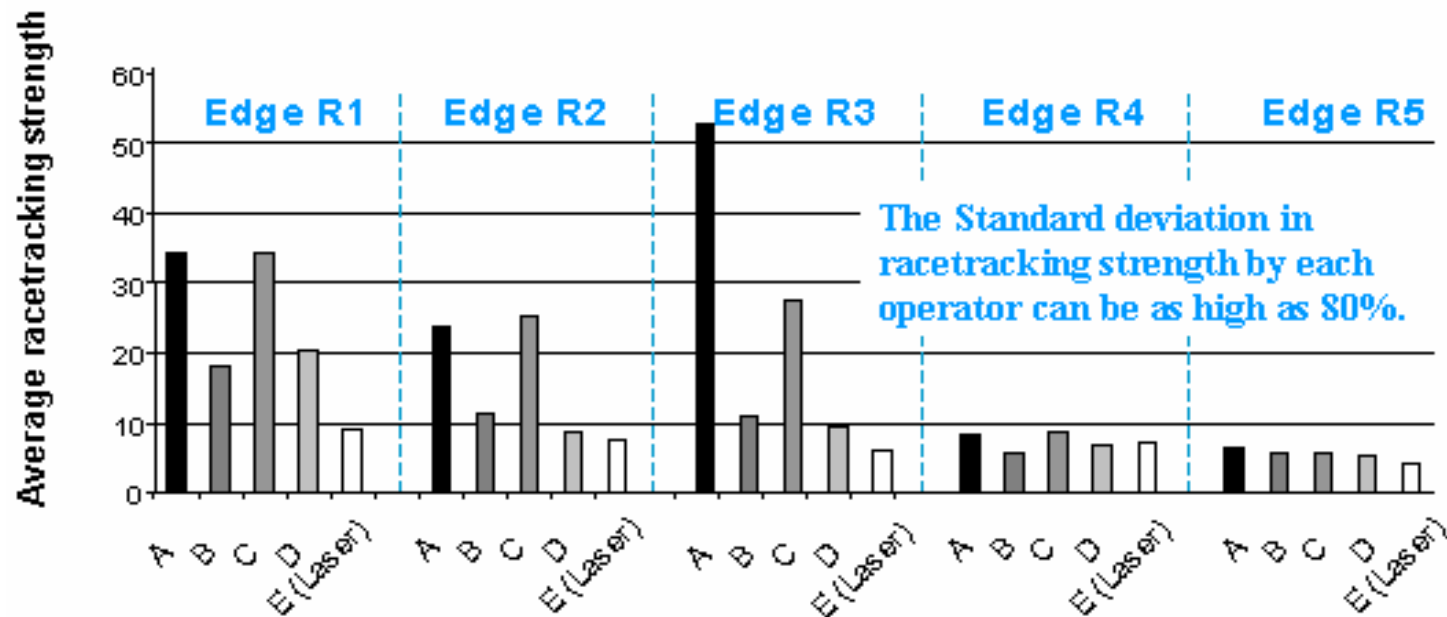


Case 5: Using SLIC to Characterize the Racetracking (Edge Effect)

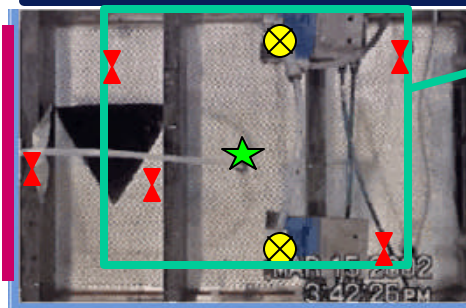


| Available Features of SLIC | Features Used |
|---|---------------|
| Gate(s) & Vent(s) Design | |
| Flow Distribution Network Design | |
| Mold Filling Monitoring & Online Characterization of Permeability/Volume Fraction | x |
| Online Mold Filling Flow Control | |

Five different operators A, B, C, D and E run 10 experiments each. A, B, C and D cut the fabrics by hands, E used a laser cutter.

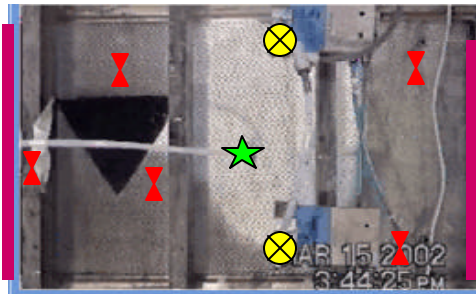


Case 6: Online Flow Monitoring & Control with SLIC



**Tekscan™ Sensor Area
(Pressure Grid Film)**

| Available Features of SLIC | Features Used |
|---|---------------|
| Gate(s) & Vent(s) Design | |
| Flow Distribution Network Design | |
| Mold Filling Monitoring & Online Characterization of Permeability/Volume Fraction | x |
| Online Mold Filling Flow Control | x |



Experimental resin arrival times
 t_0, t_1, t_2, t_3, t_4 are all collected

Disturbance Mode 29 is selected from the Database

Implement the customized control action for Mode 29

**Initial injection gate (IG)
with flow runner** —

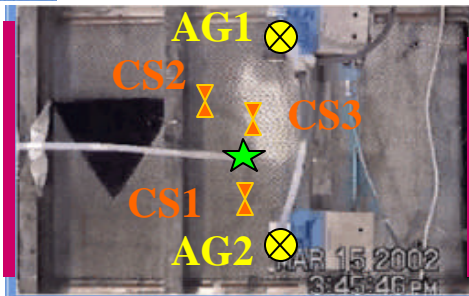
Fixed vent ★

Auxiliary gate (AG) ⊗

Disturbance detection sensor (DS) ⚡

Control action trigger sensor (CS) ⚡

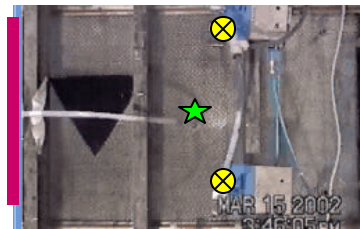
IG1



IG2

Control action Mode 29 is taking place.

- CS1 >>> Close IG2
- CS2 >>> Open AG1
- CS3 >>> Close IG1
- Vent Sensor >>> Close All Gates.



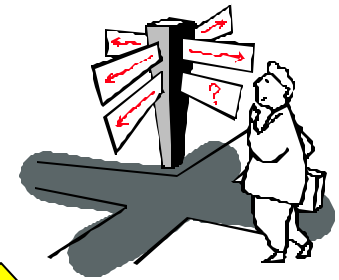
Successful injection



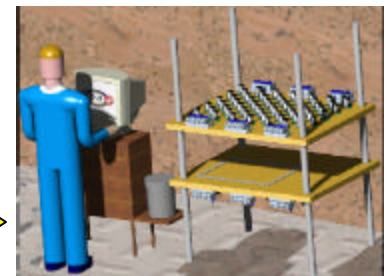
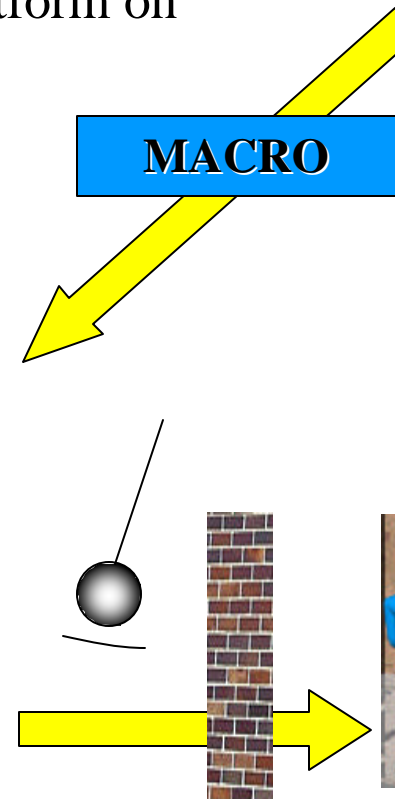
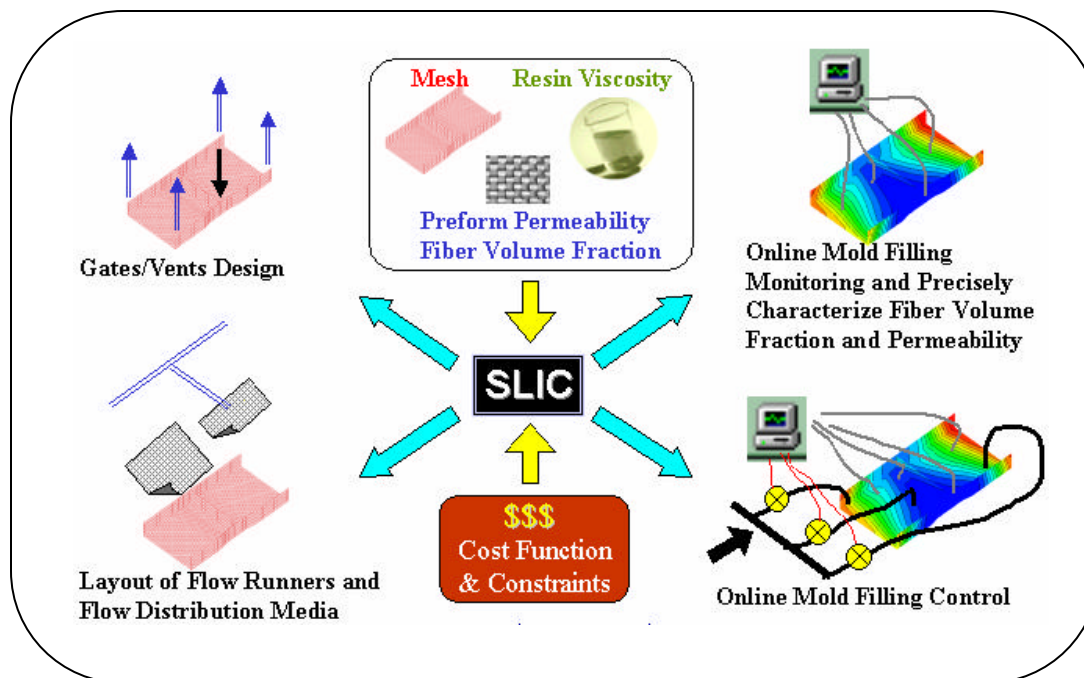
Efforts Towards User-Friendly Software



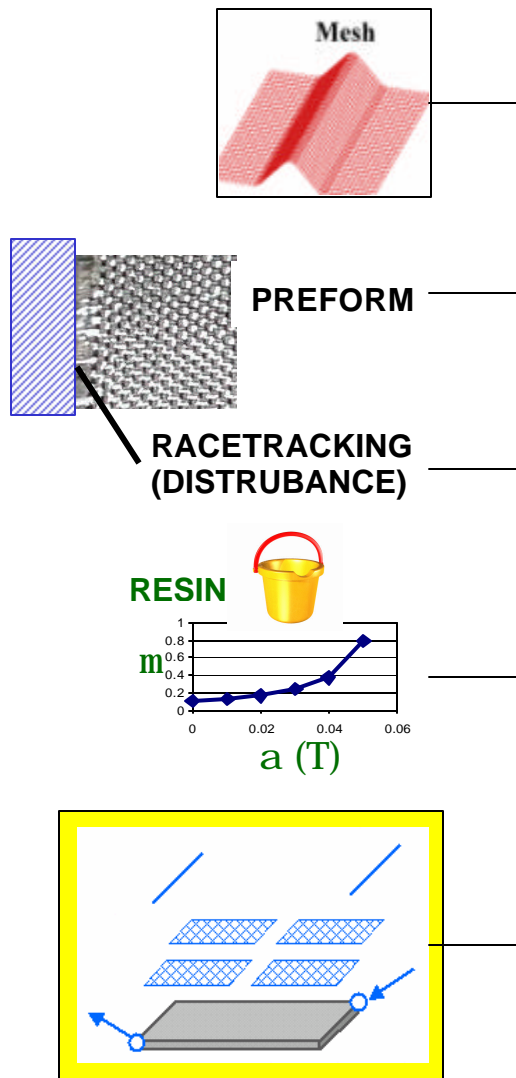
- Develop the MACRO feature which allows SLIC to be run by MACROS (either Defaulted or User Specified).
- Seamless interface with Automated RTM Platform on manufacturing floor.



Instruction 1
Instruction 2
Instruction 3
Instruction 4
Instruction 5
etc.



Summary



SLIC

AUTOMATED DESIGN

- Selection of Initial Gate and Vent Locations
- Optimization of the Flow Distribution Network
- Online Flow Sensing/Permeability Characterization System Design
- Creation of Online Flow Control Solution

Advantages of developing RTM/VARTM with SLIC

- Rapid design for RTM/VARTM.
- Less cost for process development.
- Reliable and comprehensive mold filling solution.
- Advanced flow monitoring/control technology provides the opportunity to elevate the part quality and reduce the cycle time.

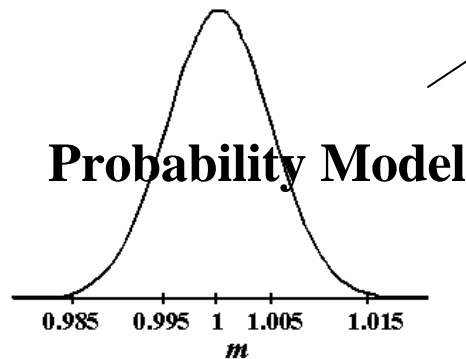
Future Work



Graphic User Interface (GUI)

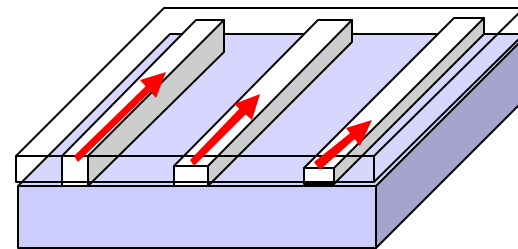
Documentation

- User Manual
- Examples
- Tutorials

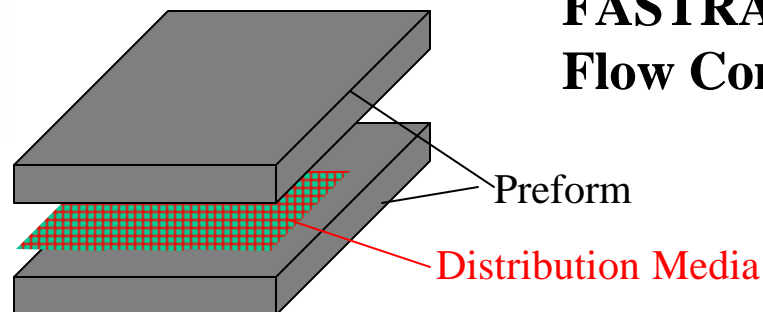


SLIC

**More Available Macros
for Users to Choose from**

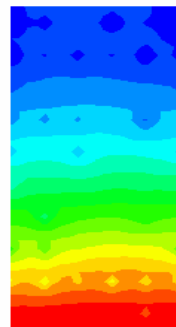
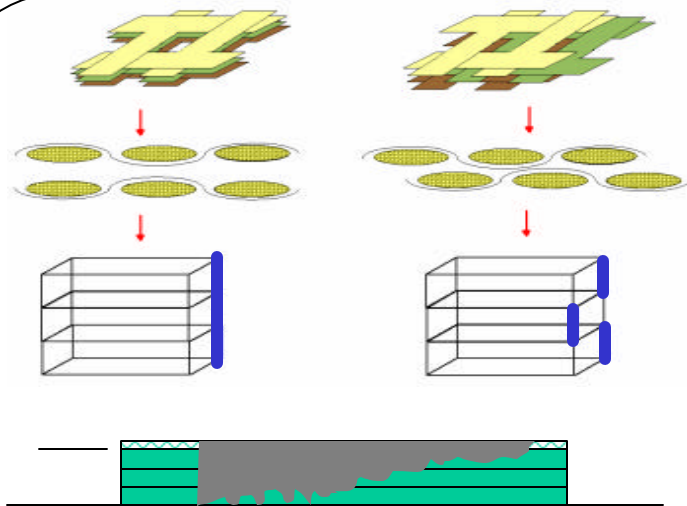


**FASTRAC
Flow Control in VARTM**

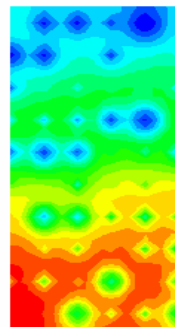


RTM Light Optimization

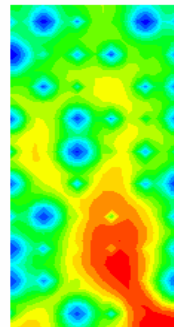
Future Work



$K_{dl} = 10^{-3} \text{ mm}^2$

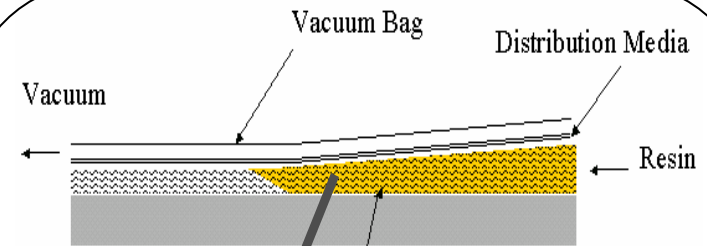


$K_{dl} = 10^{-2} \text{ mm}^2$

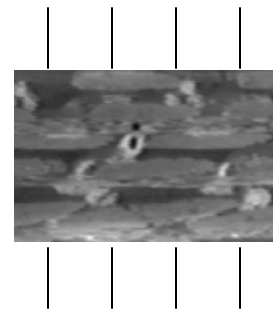


$K_{dl} = 10^{-1} \text{ mm}^2$

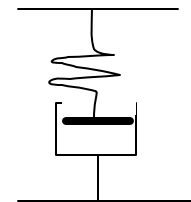
Optimize the Distribution Media ?



K and V_f Change due to the Compaction Variation in VARTM



\approx



Online Characterize Preform Compaction Model?

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